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MEASUREMENT OF OUT-OF-PLANE DISPLACEMENTS
(User's Manual for the Moiré Fringe Deflection Measurement Device)

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Final Report for Period May 1980 - November 1980

March 1981

Approved for public release; distribution unlimited.

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Instructions for use of the UDRI moiré fringe device are provided in this report. Detailed instructions for analysis of the moiré fringe patterns produced by the device are also presented. A listing of statements in a computer program named PANDIS is given. This program, written in the BASIC language is used to reduce data obtained during analysis of the fringe patterns to out-of-plane displacement data. A test problem, including sample data and output, is also presented.

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FOREWORD

The effort reported herein was performed in the Impact Physics Group under the direction of the Aerospace Mechanics Division of the University of Dayton Research Institute, Dayton, Ohio, under Contract F33615-80-C-3401, Project 1926, "Birdstrike Resistant Crew Enclosure Development Program," for the Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio. Air Force administrative direction and technical support was provided by 1Lt. Larry G. Moosman and 2 Lt. Robert Simmons, AFWAL/FIEA, the Air Force Project Managers.

The work described herein was conducted during the period from May 1980 to November 1980. Project Supervision and technical assistance was provided through the Aerospace Mechanics Division of the University of Dayton Research Institute with Mr. Dale H. Whitford, Supervisor, Blaine S. West, Project Engineer.

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INTRODUCTION

Certain experiments and tests require the measurement of out-of-plane motions of target surfaces. One way these measurements can be made is with use of special devices which produce moiré fringe patterns on the surface of the targets. A description of one of these devices has been provided in a previous document.[1] This document provides detailed descriptions of procedures related to the use of that device and the analysis of the resulting fringe patterns.

Although the device has been used primarily to determine the response of impulsively loaded targets of fairly large area (1500 to 2000 cm^2), information provided in this document also applies to analysis of data from surfaces of smaller area and surfaces subjected to slowly applied or static loads. In all cases, deflection data are obtained after analysis of photographs of individual fringe patterns.

A computer program named PANDIS is used to assist in the reduction of fringe pattern data to displacement data. This program, written in the BASIC language, is designed for use from a remote time-shared computer terminal. Section II of this document provides a brief description and instructions for use of the device. Sections III, IV, and V provide detailed data reduction instructions, a description of program PANDIS (including a listing of program statements), and a sample problem and the resulting printout, respectively.

(1) Piekutowski, A. J., A Device to Determine the Out-of-Plane Displacement of a Surface Using a Moiré Fringe Technique, AFWAL-TR-81-3005, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, OH, May 1981.

SECTION II
USE OF MOIRÉ DEVICE

As constructed, the moiré device, shown schematically in Figure 1, simply generates a system of light and dark bands which are fixed in space relative to the moiré device. The light and dark bands are apparent to the viewer only when the system of bands is interrupted by a target surface. A critical orientation of the target surface with respect to the moiré device is not required since the initial shape of the target surface can always be reconstructed after analysis of the fringe patterns.

An illustration of the technique used to produce the moiré patterns is presented in Figure 2. As shown in this figure, the optical system on the right (Projection System) projects an image of the Ronchi ruling in the system onto the target surface. The lens in the left optical system (Viewing System) focuses an image of the target and projected ruling onto the Ronchi ruling in the viewing system. A moiré pattern is produced where the image of the projected ruling is superimposed on the viewing system Ronchi ruling. A camera, with its lens focused on the composite image, is used to photographically record the moiré pattern.

Analysis of raw data is facilitated by exercising reasonable care during setup of the moiré device. Attention is drawn to the relationship of the shaded regions adjacent to the rays (boundaries between clear and opaque areas of Ronchi ruling) shown in Figure 2. The regions shown are adjacent to the optical axes of the projection and viewing systems. When the rays associated with these regions and the target surface intersect simultaneously, a dark band will appear at the target surface. This particular dark band is identified as fringe zero. Identification of the rays which produce fringe zero is facilitated by heavy locator lines

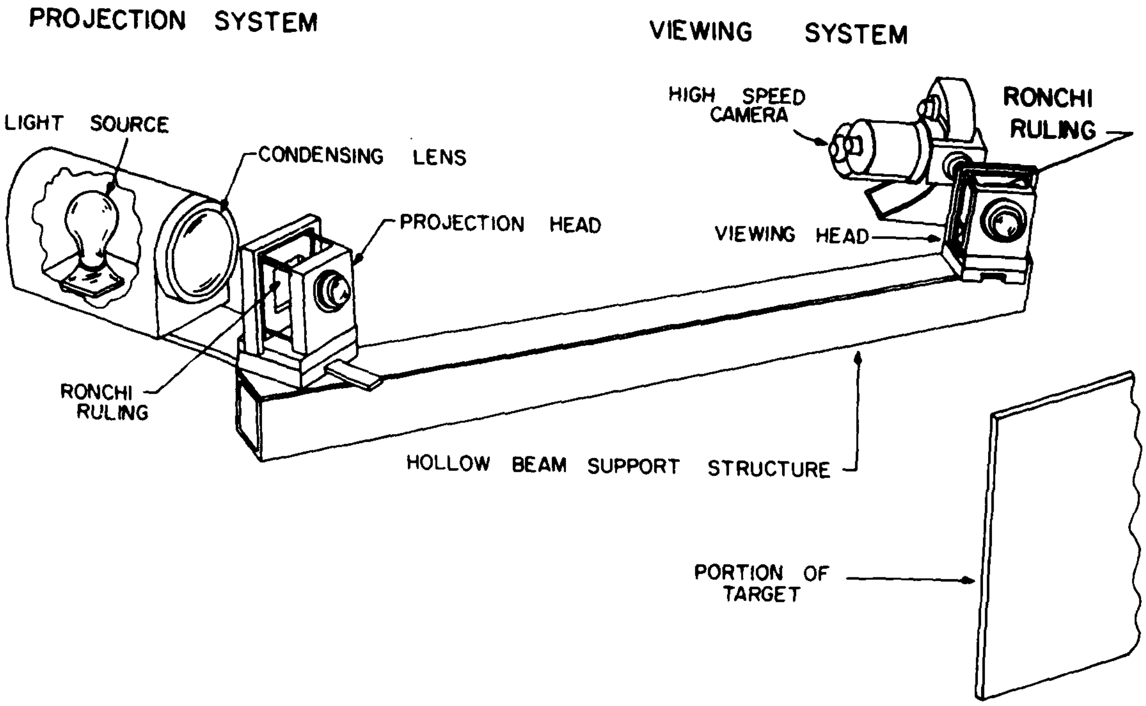

Figure 1. Schematic View of Moiré Device Illustrating Components and Their Relationship to Target.

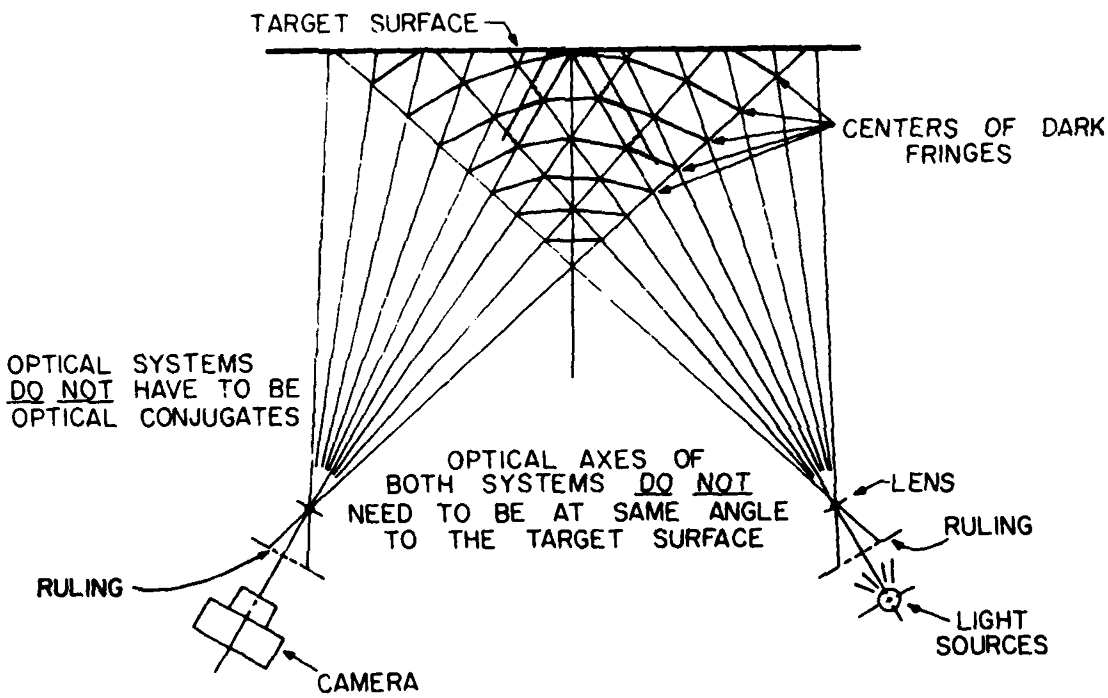

Figure 2. Technique Used to Produce Moiré Patterns.

placed on the Ronchi rulings. Relative positions of the locator lines in the various dark bands of the moiré pattern are used to establish the direction which the moiré device must be moved to produce the desired target-device relationship. The positions of the locator lines are shown for a number of fringe surfaces in Figure 3. The coordinate system and fringe numbering convention which was adopted for use during subsequent data reduction procedures are also shown in this figure.

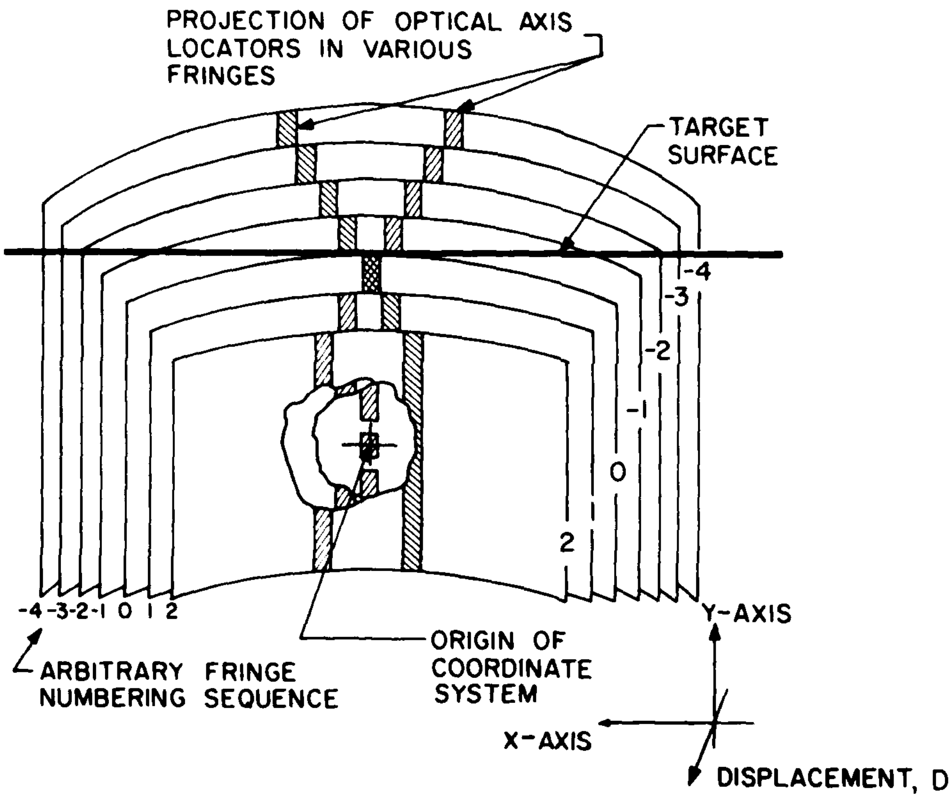

Figure 3. Arbitrary System of Identifying Fringes and Coordinate System Used in Analysis of Fringe Patterns. In this figure, the reference plane is parallel to the X-D plane. Note the position of locator lines in each fringe.

Information presented in Figure 4 is used to illustrate relationships between the various device parameters which must be determined for correct interpretation of the resultant fringe patterns. However, one important difference between the device and the illustration in Figure 4 exists. For purposes of simplifying presentation, the Ronchi ruling has been shown <u>between</u> the appropriate lens and the target rather than <u>behind</u> the lens, e.g., Figures 1 and 2. Positioning the Ronchi ruling as shown in Figure 4 merely facilitates a graphical presentation of the rays used to determine the location of the dark bands. For consistency of illustration, the lens on the right side of Figure 4 corresponds to the viewing lens of Figure 2 (on the left).

Selection of nominal characteristics of various optical components used in the device is made during design of the device. Determination of actual characteristics of these components is made during alignment and assembly of the device. The six parametric constants determined during assembly of the device--α_L, α_R, R_L, R_R, P_L, and P_R--are shown in Figure 4. These constants are used to uniquely specify the locations of the various dark bands produced by the moiré device. Following is a brief description of each of these parameters. Subscripts R and L refer to the right and left side of Figure 4.

Parameter	Description
α	Angle optical axis makes with X-axis
R	Normal distance from center of lens to X-axis or target surface (or tangent to target surface in case of curved targets). In actual practice this value is calculated using the relationship shown in Figure 4 and the appropriate values of α and the distance, d, which was measured during alignment of the individual heads.

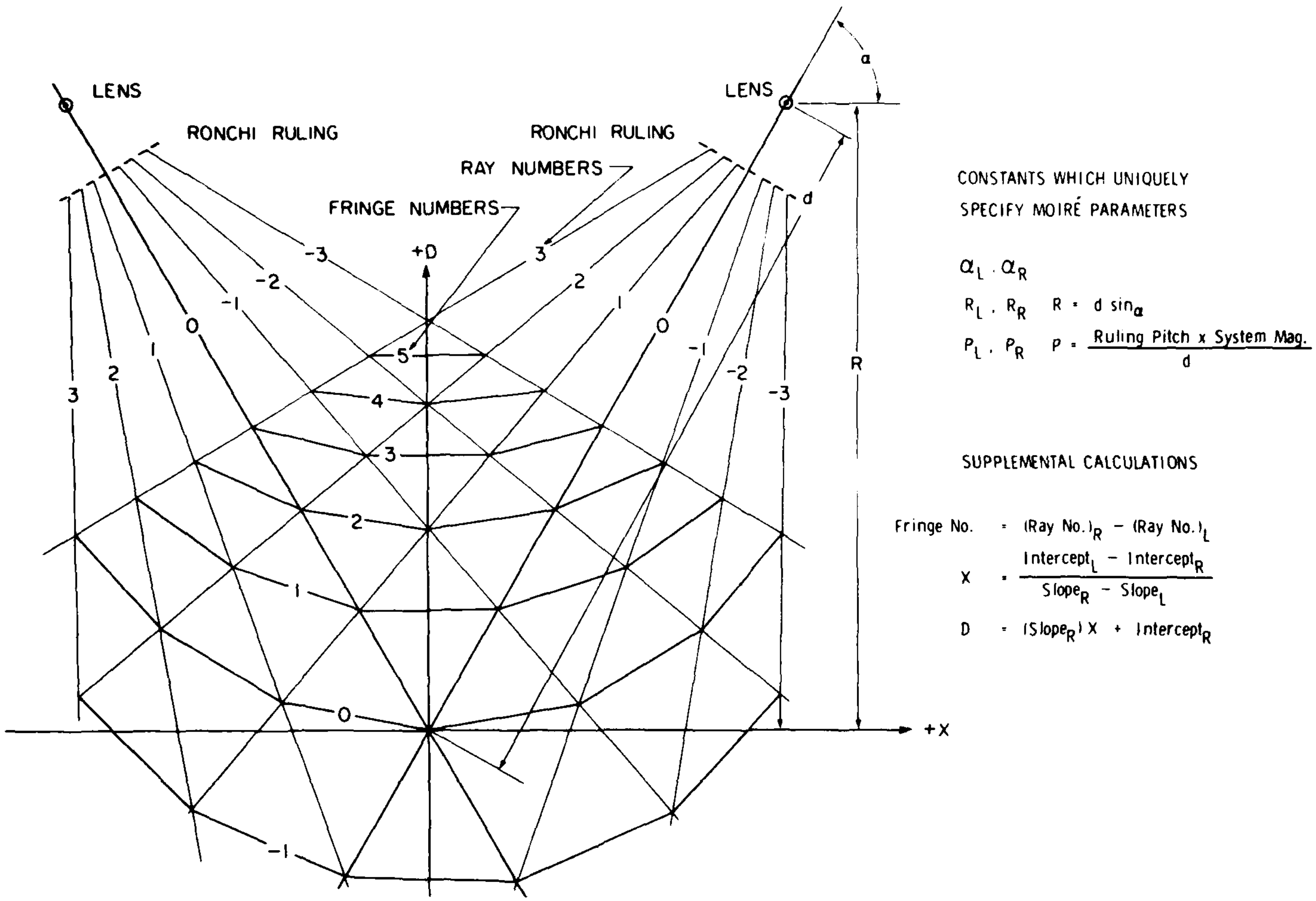

Figure 4. Graphical Representation of Rays and Procedures Used to Mathematically Reconstruct the System of Dark Bands Produced by the Moiré Device.

Parameter	Description
P	A pseudopitch used when determining, in slope-intercept form, the equations of lines representing the various rays. This dimensionless value is determined, as shown in Figure 4, using the Ronchi ruling pitch (furnished by Ronchi ruling manufacturer), the system magnification (measured during the alignment of the individual heads), and the previously mentioned distance, d.

Target surfaces shown in the four figures just presented are represented as planar surfaces which are tangent to fringe zero. This orientation is not required for satisfactory operation of the device, and practically speaking, is rarely achieved. When the device is used with convex or concave surfaces, the preferred orientation of the device has the displacement axis of Figure 3 coincide with a line normal to a plane tangent to the target surface at the point where intersection of the X-axis interruptions in the locator lines occurs. The relationship of the moiré device displacement axis (fixed by optical components in the moiré device) and a line normal to the target at the point of tangency just described is the preferred orientation of the device and target for all applications since it facilitates identification of fringe zero. When the device is mounted independent of the target, the user must carefully position the device for each test to insure this orientation is achieved as closely as possible. In other applications, e.g., measurement of aircraft transparency deflections, the moiré device may be installed in mounts which may or may not provide for adjustment of the relationship of the device to the target surface. In these cases, the general relationship of the target and the device is fixed during design of the device mounting hardware.

Most uses of the moiré device require some preparation of the target surface. Typical preparations consist of the application of a reflective coating, usually white paint, and the installation of fiducial marks on the reflective screen. The fiducial marks are used to provide data for film magnification determinations. A suggested fiducial line layout is presented in Figure 5. Use of X's rather than short line segments as reference points on the horizontal axis eliminates the likelihood of one or more of the line segments being obscured by the lines in the projected or viewed Ronchi ruling.

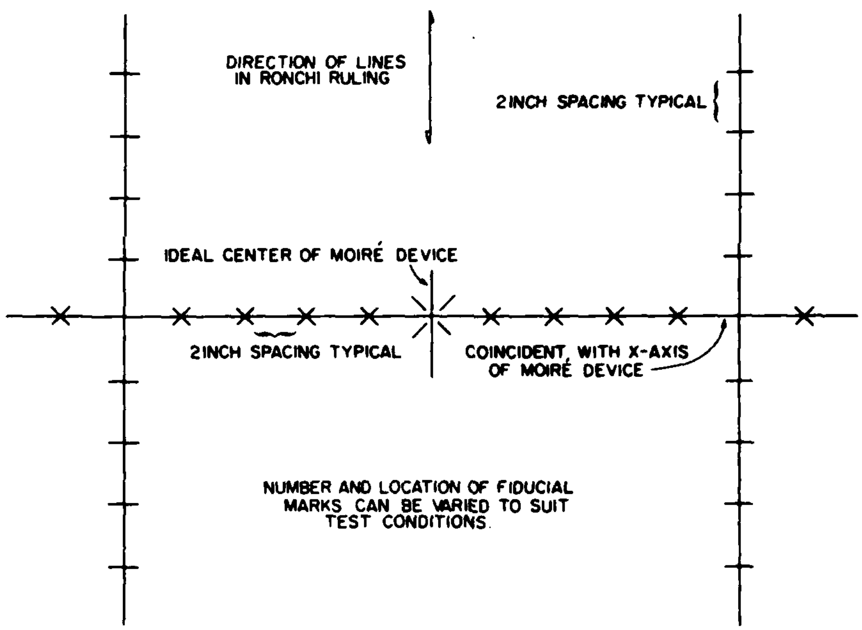

Figure 5. Suggested Fiducial Pattern for Use with Moiré Device.

SECTION III
DATA REDUCTION

Data used to generate deflection information are obtained from various photographs taken during the experiments or tests. A single photograph may be analyzed in the case of a statically loaded target. When the target is impulsively loaded, data are taken from photographs of selected frames of a high-speed film of the transient fringe patterns. Measurements of the locations of timing marks placed on the high-speed films are used to determine the framing rate of the camera and the time interval between successive fringe patterns for these dynamic events. In this section, detailed instructions for making a variety of measurements are provided. The measurements are described and presented in the order in which they are entered into the computer program. A listing and description of sample data items is presented in Section V. The first data entries consist of specific moiré device parameters and information unique to the test. An explanation of each of these data items is given in Section V.

Although the original negative film may be used for data reduction purposes, analysis of the moiré patterns is greatly facilitated by using enlarged prints of the individual frames. In the case of multiple prints, it is extremely important that all frames taken from a data film be printed at the identical magnification. Data used to obtain film magnification information are taken from pre-event photographs. Post event photographs are used to obtain measurements of fringe location and, ultimately, target displacement. Since the fiducial lines are applied to a surface which is in motion during the event, film magnification information taken from post event frames should be regarded as suspect.

Because the axis of the viewing system is at an angle to the target surface, distortion of the image produced at the viewing system Ronchi ruling occurs. Consequently, magnification of the target image varies continuously in the horizontal (X) and vertical (Y) directions. Since out-of-plane displacement data are derived from measurements taken from the film, conversion of measured dimensions (film) to true dimensions (target) requires that the variation in film magnification be accounted for properly.

Film magnification along the X-axis is determined using measurements taken from one or more of the frames immediately preceding the event. (Only one set of averaged values is entered into the program, however.) Profiles other than those along the X-axis are usually taken from sections parallel to the X-axis and through the short horizontal lines on the two long vertical lines of the fiducial system (Figure 5). Magnification in the Y direction is thus treated graphically and no further corrections are required. An illustration of a modified target-viewing head relationship is presented in Figure 6. In this figure, film normally in the camera is shown in the plane of the viewing head Ronchi ruling. A view of the undistorted target surface and fiducial system is shown in the upper right of this figure. A view of the distorted image produced on the film is shown at the lower right of Figure 6. Also shown in this figure is the position of the interruption in the locator line with respect to the X-axis.

As shown in the lower right portion of Figure 6, the locator line (ray zero) does not coincide with the center of the fiducial pattern and an offset of unknown magnitude results. The magnitude of this offset and actual film magnification data are determined graphically using measured values taken from the pre-event photographs. All measurements are made with respect to the locator line of the viewing head. This line will always appear as a straight line in all photographs. Raw film magnification data consist of a table of measured distances to known points (X's on the horizontal fiducial line) and the

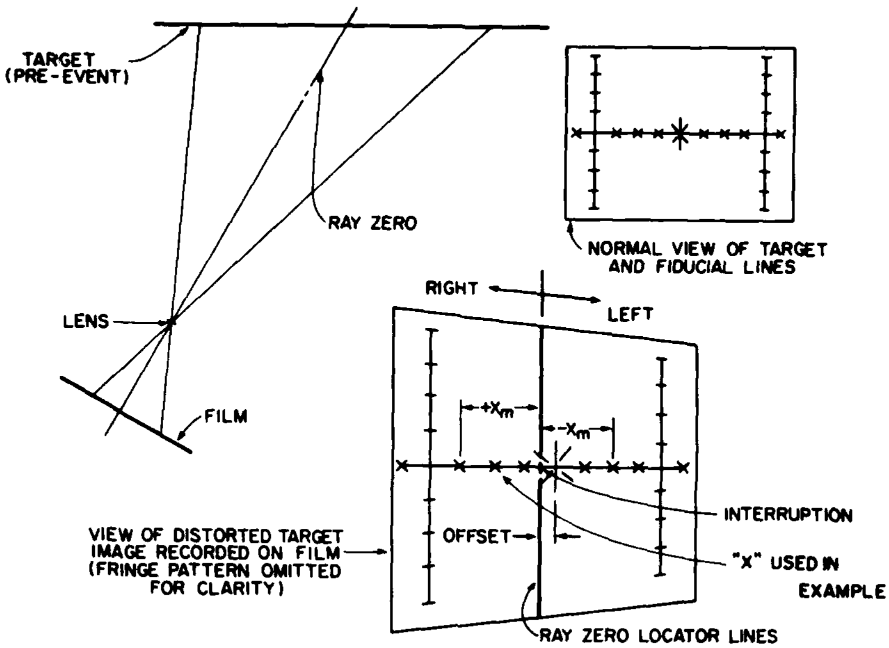

Figure 6. Illustration of Technique which Produces a Distorted Image of Target Surface and Fiducial Pattern. Reference to Figures 3 and 4 will clarify the apparent reversal of right and left in the distorted image of the target surface and fiducial pattern.

corresponding true distance to these points. Measured distances to the right of the locator line have positive values and measured values to the left of the locator line have negative values. When these data are plotted as shown in Figure 7, the magnitude of the offset between the center of the moiré device and the center of the fiducial pattern corresponds to the true distance between the parallel lines representing the center of the moiré device and the center of the fiducial system.

The value of offset thus obtained is used to "correct" the true values and generate a table of "corrected" film magnification data which are entered into program PANDIS. For example, the true position of the second X to the right of center of the fiducial pattern is +4 inches. This true value is corrected by subtracting the algebraic value of the offset from the true position of the fiducial mark, i.e., +4 - (+1.2) = +2.8. All other true values are corrected in a like manner.

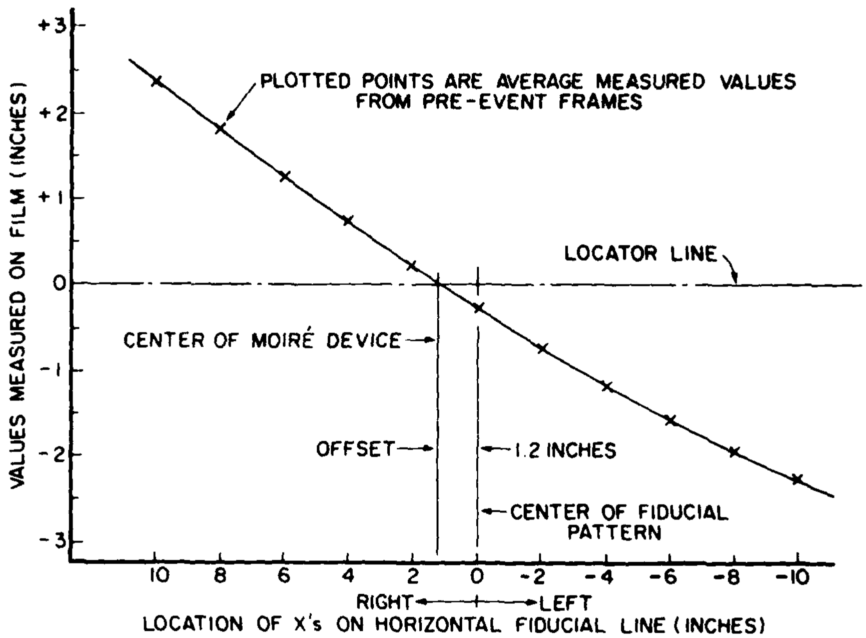

Figure 7. Illustration of Graphical Method Used to Determine Offset and "Corrected" Film Magnification Data.

The measured distance from the locator line to this X (and all other X's in the photograph) remains unchanged.

Processing of raw film magnification data in PANDIS yields the coefficients of a second order polynomial. Subsequent conversion of measured distances taken from data frames to true distances is accomplished by evaluating the polynomial using the measured values as the independent variable.

The framing rate of the high-speed camera, in pictures per second (pps), is determined for that portion of the high-speed film in which response of the target is recorded. Framing rate is determined from measurements illustrated in Figure 8. In this figure, timing mark zero was arbitrarily selected as the sixth mark before the frame in which response of the target was first observed. In practice any of the several marks appearing before this frame may be selected as timing mark zero. All subsequent measurements are made with respect to timing mark

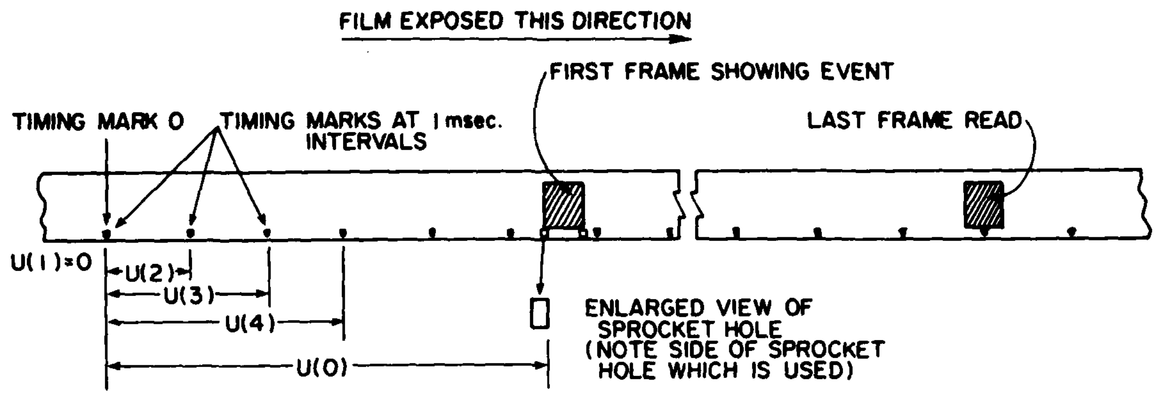

Figure 8. Illustration of a Portion of High-Speed Film Showing Measurement Points for Film Speed Determination.

zero. In program PANDIS, the time to successive marks, R( ), and the corresponding measured distances, U( ), are entered as data pairs and used in conjunction with certain physical characteristics of 16 mm film to determine the coefficients of a polynomial which yields the instantaneous framing rate of the camera as a function of frame number.

The frame of film immediately before the frame in which response of the target is observed is identified as frame zero. Frames exposed after frame zero are numbered sequentially in ascending order. The first measurement to be taken, U(0), is used to determine the location of frame zero with respect to timing mark zero. The other measured distances, U(1), U(2), U(3), etc., are used to determine the actual framing rate of the camera. Note that the distance to timing mark zero, U(1), is zero and entered accordingly in statement 100 of the Sample Data (Section V).

Since the system of dark bands generated by the moiré device is unique for the set of system parameters, displacement of a target at any point can be determined if the X-coordinate and fringe number of the point are specified. The X-coordinate and fringe number are obtained from analysis of a photograph of the fringe pattern. A simulated photograph of an ideal target and fringe pattern is presented in Figure 9. The intended use of the out-of-plane displacement data determines the number of measurements taken from the photograph. If the deflected shape along one section is required (usually along the horizontal fiducial line), measurements are taken where the dark bands intersect the fiducial line. If a map of the deflected surface is desired, additional profiles are obtained along sections parallel to the horizontal fiducial line. Examples of both types of measurements are illustrated in Figure 9.

Analysis of photographs begins with identification of the various dark bands in the moiré pattern. Use of the locator

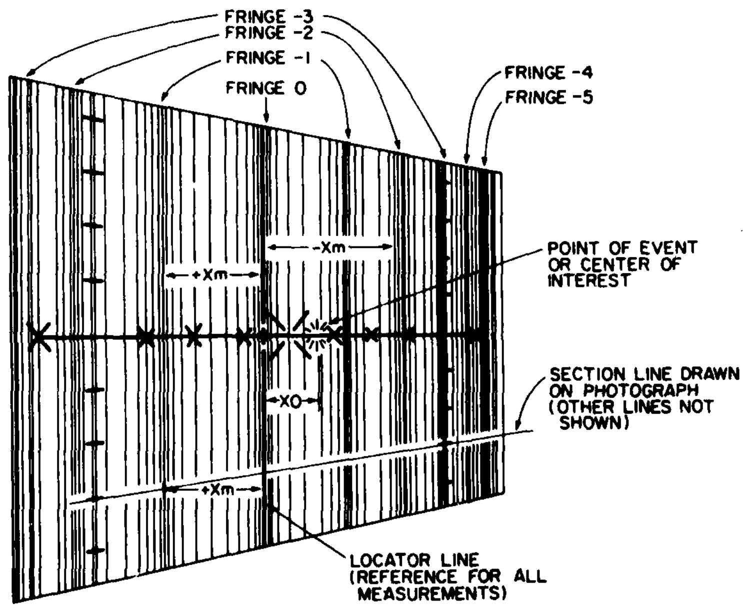

Figure 9. Simulated Photograph of Ideal Moiré Pattern Showing Various Measurement Locations.

lines aids in the identification of fringe zero. Study of Figures 3 and 4 will assist in the identification of all other dark bands in the pattern. If deflected surface data are required, lines are drawn on the photograph through the short horizontal lines which are part of the vertical fiducial lines. Finally, measurement of the various distances is made. As shown, these distances are measured from the center of the dark band to the locator line. Note that all measurements are made perpendicular to the locator line and that the correct algebraic sign of the measured value must be observed.

Data for the measured points along each section line are entered as fringe number-measured value pairs beginning with the pair at the left of the photograph and ending with the pair at the right of the photograph. When data for a number of sections from a photograph are to be entered, data from the uppermost section are entered first; order of entry proceeds successively to the lower sections.

Procedures used in the collection of fringe number-measured value data are identical for the pre-event and post event photographs with one exception. An additional measurement is taken from the first post event frame or the pre-event frame if the target is suitably identified. This measurement, XO in Figure 9, is the distance from the locator line to the point of the event or the center of the area of interest. The value of XO is entered into PANDIS prior to entry of the pre-event and post event data.

Examination and study of the sample data in Section V should clarify and further the program user's understanding of data entry procedures used with PANDIS.

SECTION IV

PROGRAM DESCRIPTION

1. PROGRAM USAGE

Program PANDIS consists of a main program and two subroutines, LSQ and COR. The main program directs reading of input variables, raw data, order of processing raw data, and printing of results. Subroutine LSQ is called upon several times during execution of the main program to fit data sets to least-squares polynomials. Subroutine COR is called after each raw data pair has been read and processed to yield a displacement value unique to the fringe number and X-coordinate of the data pair. In subroutine COR, the initial value of displacement is examined and corrected, if necessary, for magnification errors which are introduced when the target surface (hence, measurement plane) has been displaced a sufficient distance from the initial reference (pre-event) plane. A simplified flow chart for the main program is presented in Figure 10.

Input variables and test peculiar data are read at the beginning of the main program. Certain of these data are used to characterize, in tabular form, the location (in displacement, D, and X-coordinates) of the fringes which were observed in the test film. In the next portion of the program, data used to determine film magnification and speed are processed to yield least-squares polynomials which describe the variations, with distance and time, respectively, of these film parameters. Work on actual fringe pattern data begins with data taken from the pre-event frame. Individual sets of X-D data taken from this frame are fit to least-squares polynomials which attempt to describe the shape of the undeflected target surface along a particular measurement section line. At the completion of printout of the results of the first fit, the user is asked if the next higher order of fit should be made. A positive response results in another pass through subroutine LSQ. Printout of

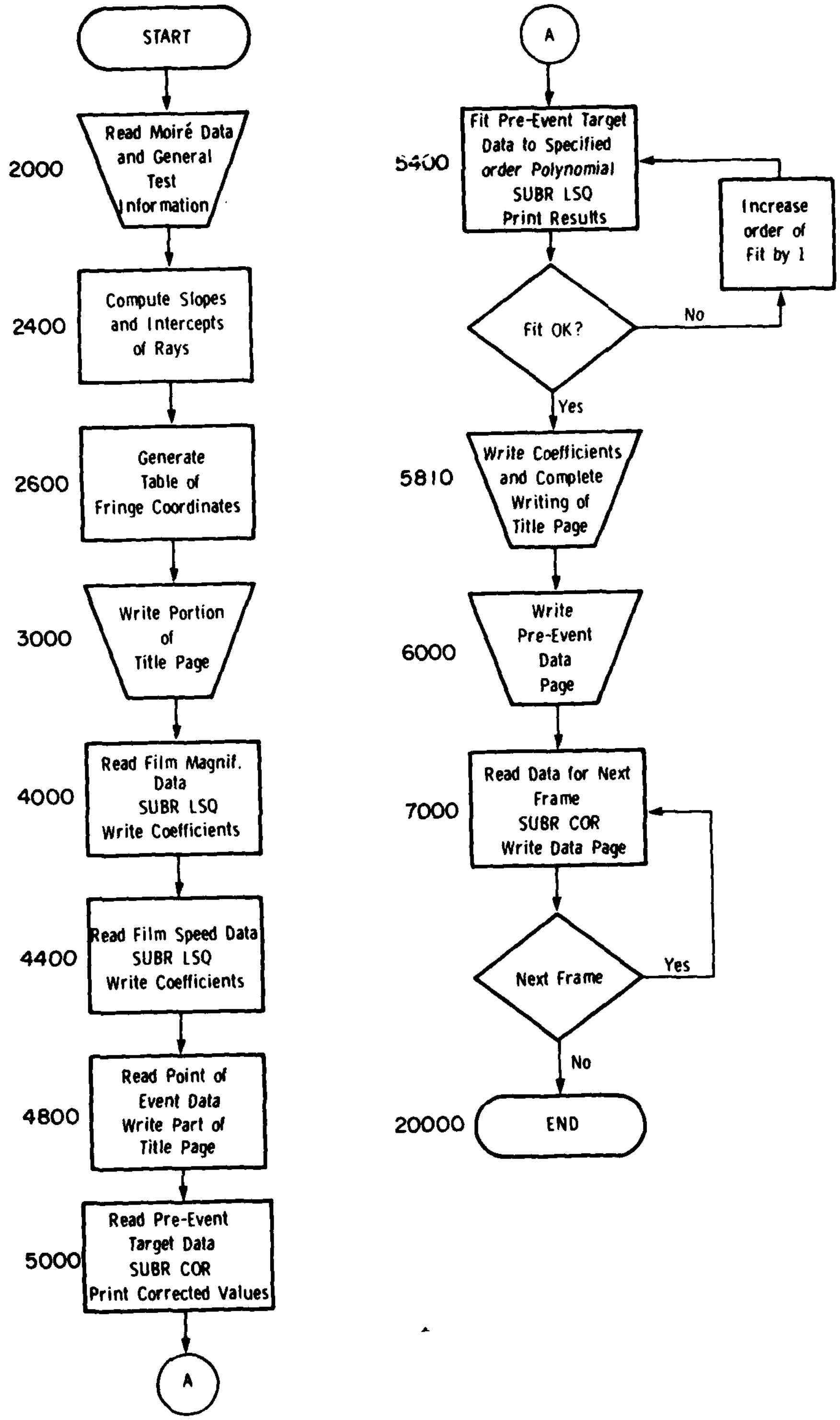

Figure 10. Flowchart for Program PANDIS. Initial values for range of program statement numbers in which specific operations are performed are shown at left of flowchart symbols.

the results of this fit is again followed by the opportunity to request the next higher order of fit. After various orders of fit have been examined, the user is asked to select that order of polynomial which best describes the pre-event panel shape. Upon receipt of a reply, control of processing of data from post event frames and the printing of results is returned to the main program.

2. DESCRIPTION OF VARIABLES

Following is a listing (and brief description) of the simple variables, arrays, and string variables used in program PANDIS. Where appropriate, units and applicable reference figures are included in this listing.

Simple Variables

A1 - Angle, α_R, which optical axis of R.H. optical system makes with X-axis, radians (Figure 4).

A2 - Angle, α_L, which optical axis of L.H. optical system makes with X-axis, radians (Figure 4).

A3 - Angles which rays in R.H. optical system make with X-axis, radians.

A4 - Angles which rays in L.H. optical system make with X-axis, radians.

A5 - Angle, α, used when "correcting" displacements for magnification errors, radians (Figure 11).

A6 - Angle, β, used when "correcting" displacements for magnification errors, radians (Figure 11).

E - Standard error of estimate of least-squares fit.

F0 - Time after event, evaluated for each frame number, msec.

F1 - Largest positive fringe number used in evaluation.

F2 - Largest negative fringe number used in evaluation.

F3 - Average framing rate of camera over an arbitrary 1 msec interval, I_o, pps.

F4 - Average framing rate of camera over the arbitrary 1 msec interval, $I_o + 1$, pps.

F5 - A_0 term of polynomial describing film speed.

F6 - A_1 term of polynomial describing film speed.

F7 - A_2 term of polynomial describing film speed.

I - General operator.

I1 - Operator to sequence through all frames of film after pre-event frame.

I2 - Operator to sequence through all sections of a frame.

J - General operator.

K - General operator.

L - General operator.

M - General operator.

M1 - Order of fit desired in least-squares subroutine.

M2 - M1 + 1.

M3 - A_0 term of polynomial describing film magnification, inches.

M4 - A_1 term of polynomial describing film magnification.

M5 - A_2 term of polynomial describing film magnification, inches^{-1}.

N - General operator.

N0 - Number of frames of film to be evaluated (including pre-event frame.

N1 - N9 + 1.

N2 - Frame number.

N3 - Number of sections in a frame.

N4 - Value used to signal that insufficient data are available for a least-squares fit.

N9 - Number of rays on either side of optical axis (Figure 4).

P0 - Proportionality factor used during interpolation in X-D Tables.

P1 - Number of data pairs for a particular use of least-squares subroutine or other functions requiring knowledge of number of data pairs for a particular operation.

P7 - Page counter.

P9 - Pi (3.14159).

R1 - Normal distance from R.H. optical system lens to X-axis, mm (Figure 4).

R2 - Normal distance from L.H. optical system lens to X-axis, mm (Figure 4).

R3 - Constant used when "correcting" displacements for magnification errors, mm.

R8 - Pseudopitch of R.H. optical system (Figure 4).

R9 - Pseudopitch of L.H. optical system (Figure 4).

S - Summation in least-squares subroutine.

S0 - Calculated displacement (w/r to Moiré Device) using pre-impact data fit, mm.

S2 - Δx in "correction" of displacements for magnification errors, mm.

S6 - Temporary storage of X values, mm.

S7 - Temporary storage of D values, mm.

X0 - Point of impact w/r to centerline of Moiré Device, inches and mm (Figure 9).

Y0 - Counter in correction subroutine.

Y2 - Summation in least-squares subroutine.

Y8 - Projectile weight, variable.

Y9 - Impact velocity, variable.

Z - Absolute value of (Y2-S).

Arrays

A (,) - Coefficients obtained in least-squares subroutine.

B ( ) - Intercepts of rays in right optical system, mm.

C ( ) - Intercepts of rays in left optical system, mm.

D (,) - Displacement values in table of fringe coordinates, mm.

E (,) - Specific displacement values from pre-event frames, mm.

F ( ) - Counter number for X and D values tabulated for each fringe.

G ( ) - Storage for various X_i summations in least-squares subroutine.

H (,) - Specific fringe numbers from pre-event frames.

M ( ) - Slopes of rays in right optical system.

N ( ) - Slopes of rays in left optical system.

O (,) - Storage of coefficients of polynomials describing each section in pre-event frame. O(9,) = P1 and O(10,) = M1.

P ( ) - X-values in least-squares subroutine, inches or mm; measured values for film magnification data, inches; and measured values for post event frames, inches.

Q ( ) - Y-values in least-squares subroutine, inches or mm; true values for film magnification data, inches; and fringe numbers for post event frames.

R ( ) - Time values for film speed determination, msec and measured value for pre-event data, inches.

T (,) - Various $\Sigma x_i^m y_i$ in least-squares subroutine.

U ( ) - Measured distances for film speed determination inches (Figure 8), and fringe number for pre-event data.

V (,) - Inverse of Y(,) in least-squares subroutine.

W (,) - Specific X-values from pre-event frame, mm.

X (,) - X-values in table of fringe coordinates, mm.

Y (,) - Various Σx_i^m in least-squares subroutine.

String Variables

D$ - Date.

S$ - Shot or test identification code.

X$ - Query for next order of fit in least-squares fit for pre-event data.

P$ ( ) - P$(0) - Target description.

P$(1) to P$(9) - ST, ND, RD, TH, TH, TH, TH, TH, TH suffixes added to order of fit to yield 1st, 2nd, etc.

P$(10) - Projectile description.

P$(11) to P$(20) - Section location designators.

3. PROGRAM LISTING

Following is a listing of the BASIC statements which comprise program PANDIS. The program, as listed, was run on a UNIVAC 90/80-3 computer using the sample data included in the next section to produce the printout presented at the end of the next section. The listing has been separated into a number of statement groups. In general, each group corresponds to one of the operations shown on the flowchart in Figure 10. Where appropriate, a short explanation of the function of each group of statements is presented prior to the listing of statements.

```
0 REM - STATEMENT NUMBERS 1 THROUGH 999 ARE AVAILABLE FOR DATA
```

See Sample Data (Section V) for format requirements.

The following statements allocate storage for the variously named arrays.

```
1000 DIM A(10,1),B(200),C(200),D(100,30),E(30,10)
1010 DIM F(200),G(10),H(30,10),M(200),N(200),O(10,10)
1020 DIM P(50),P$(20),Q(50),R(50),T(10,1)
1030 DIM U(50),V(10,10),W(30,10),X(100,30),Y(10,10)
2000 REM   PARAMETRIC CONSTANTS FOR MOIRE APPARATUS
2010 READ R1,R2,N9,R8,R9
2020 READ A1,A2,F1,F2,N3
2030 P9=3.14159
2040 N1=N9+1
2050 FOR I=1 TO 9
2060 READ P$(I)
2070 NEXT I
2080 R3=R1/TAN(A1)
2090 FOR I=11 TO N3+10
2100 READ P$(I)
2110 NEXT I

2200 REM - READ GENERAL INFORMATION REGARDING SHOT
2210 READ S$,D$,P$(0)
2220 READ P$(10),Y8,Y9,N0
```

In the next operation, the general form of equation used to determine the slopes of the various rays is:

$$m = \tan \theta$$

where m is the slope of the ray and θ is the angle which the ray makes with the X axis. The D-intercept, b, of each ray is computed using the following relationship and values illustrated in Figure 4.

$$b = R - \left(\frac{R}{\tan \alpha}\right) m$$

In the program, care is taken to insure that the proper algebraic signs are observed during computation of the various values.

```
2400 REM - DETERMINE SLOPES AND INTERCEPTS OF ALL RAYS
2410 FOR I=-N9 TO N9
2420 J=I+N1
2430 A3=ATN(I*R8)
2440 A4=ATN(I*R9)
2450 M(J)=TAN(A1-A3)
2460 B(J)=R1-((R1/TAN(A1))*M(J))
2470 N(J)=-TAN(A2+A4)
2480 C(J)=R2+((R2/TAN(A2))*N(J))
2490 NEXT I
```

Before the coordinates of the intersections of rays are tabulated, the fringe number of the intersection is checked to determine whether or not it falls within the range of fringe numbers that appeared on the data photographs. Intersections for fringe numbers which lie outside the range are not computed. Computation of the fringe numbers and X and D coordinates of the various intersections is made using relationships given in Figure 4.

```
2600 REM - DETERMINE AND TABULATE INTERSECTIONS OF ALL RAYS
2610 FOR I=1 TO (F1+ABS(F2)+1)
2620 X(0,I)=F1+1-I
2630 D(0,I)=F1+1-I
2640 F(I)=0
2650 NEXT I
2660 FOR I=-N9 TO N9
2670 I1=I+N1
2680 FOR J=-N9 TO N9 STEP 2
2690 J1=J+N1
2700 IF (I-J)>F1 THEN 2760
2710 IF (I-J)<F2 THEN 2760
2720 K=F1-I+J+1
2730 F(K)=F(K)+1
2740 X(F(K),K)=(C(J1)-B(I1))/(M(I1)-N(J1))
2750 D(F(K),K)=M(I1)*X(F(K),K)+B(I1)
2760 NEXT J
2770 NEXT I


3000 REM - START PRINTOUT OF TITLE PAGE
3010 LIST USING 9010
3020 LIST USING 9670
3030 LIST USING 9020,S$
3040 LIST USING 9030,D$
3050 LIST USING 9040,P$(0)
3060 LIST USING 9050,P$(10)
3070 LIST USING 9060,Z8
3080 LIST USING 9070,Z9
3090 LIST USING 9080,N0-1
3100 LIST USING 9090
3110 LIST USING 9100
3120 LIST USING 9110
3130 LIST USING 9120
3140 LIST USING 9130
3150 LIST USING 9140
3160 LIST USING 9150
3170 LIST USING 9160
```

Film magnification data are fit to a specified order of polynomial in subroutine LSQ. The coefficients of the resulting polynomial are printed and stored for later use.

```
4000 REM - READ FILM MAGNIFICATION DATA AND FIT TO A 2ND-ORDER POLYNOMIAL
4010 READ P1,M1
4020 FOR I=1 TO P1
4030 READ P(I),Q(I)
4040 NEXT I
4050 GOSUB 10000
4060 M3=A(1,1)
4070 M4=A(2,1)
4080 M5=A(3,1)
4090 LIST USING 9170,M3,M4,M5,E
```

In statements 4450 and 4480, measured values taken from the film (Figure 8) are used to compute "instantaneous" framing rates, F3 and F4, for successive time intervals. These computations are tailored to 16 mm film (40 frames per foot) with timing marks applied to the film at 1 msec intervals. Successive "instantaneous" framing rates are averaged to provide the framing rate data which are fit to a polynomial in subroutine LSQ. Coefficients of the polynomial are printed and stored for later use.

```
4400 REM - READ FILM SPEED DATA AND FIT TO A 2ND-ORDER POLYNOMIAL
4410 READ P1,M1,U(0)
4420 FOR I=1 TO P1
4430 READ R(I),U(I)
4440 NEXT I
4450 F3=((U(2)-U(1))*10000)/(3*(R(2)-R(1)))
4460 FOR I=1 TO P1-2
4470 P(I)=(U(I+1)-U(0))*10/3
4480 F4=((U(I+2)-U(I+1))*10000)/(3*(R(I+2)-R(I+1)))
4490 Q(I)=(F3+F4)/2
4500 F3=F4
4510 NEXT I
4520 P1=P1-2
4530 GOSUB 10000
4540 F5=A(1,1)
4550 F6=A(2,1)
4560 F7=A(3,1)
4570 LIST USING 9180,F5,F6,F7,E


4800 REM - READ, COMPUTE, AND PRINT REAL VALUE OF POINT OF IMPACT
4810 READ X0
4820 X0=(M3+M4*X0+M5*X0**2)*25.4
4830 LIST USING 9670
4840 IF SGN(X0)>0 THEN 4870
4850 LIST USING 9190,ABS(X0)
4860 GOTO 4880
4870 LIST USING 9200,ABS(X0)
4880 LIST USING 9260
4890 LIST USING 9270
4900 LIST USING 9280
4910 LIST USING 9290
4920 LIST USING 9680
```

Raw data for the pre-event frame are processed on a section-by-section, point-by-point basis. After each fringe number-measured value pair has been read, the measured value is processed to compensate for film magnification errors and to convert units of measurement. Using the fringe number and X-coordinate as access controls, a displacement value is obtained from a linear interpolation of tabulated fringe coordinates. These initial values of X and D are stored and then processed in subroutine COR to determine the magnitude of correction, if any, which must be applied to the raw values. After the corrections for film magnification have been made, the raw and corrected values (and a count of the number of adjustments made in subroutine COR) are printed at the terminal.

```
5000 REM    READ FRINGE NO.,MEASURED X DATA FOR PRE IMPACT PANEL DATA
5010 FOR I2=1 TO N3
5020 PRINT
5030 PRINT P$(I2+10)
5040 PRINT
5050 PRINT USING 9410
5060 PRINT USING 9415
5070 PRINT
5080 READ P1
5090 FOR I=1 TO P1
5100 READ U(I),R(I)
5110 F(I)=(M3+M4*R(I)+M5*R(I)^2)*25.4
5120 S6=F(I)
5130 J=P1-U(I)+1
5140 FOR K=1 TO N9+1
5150 IF X(K,J)<F(I) THEN 5170
5160 NEXT K
5170 F0=(X(K-1,J)-F(I))/(X(K-1,J)-X(K,J))
5180 D(I)=D(K-1,J)+F0*(D(K,J)-D(K-1,J))
5190 S7=D(I)
5200 GOSUB 15000
5210 R(I)=F(I)
5220 W(I,I2)=R(I)
5230 F(I)=D(I)
5240 H(I,I2)=F(I)
5250 U(I)=Q(I)
5260 E(I,I2)=U(I)
5270 PRINT USING 9700,F(I),S6,R(I),S7,U(I),Y0
5280 NEXT I
```

The corrected X and D data pairs for each pre-event section are fit to a second order polynomial in subroutine LSQ. Coefficients of the resulting polynomial as well as the measured and fitted data are printed at the terminal and the user is asked if the next higher order of fit is desired. A positive response results in a repetition (at the next higher order) of the curve fitting and printing process. A negative response terminates the procedure and the user is asked to specify the order of fit which will be used to describe the particular section. Pre-event displacement data are fit to a polynomial to provide a continuous functional relationship which is used during determinations of the relative displacement of the panel for each of the varying X values from the post event data.

```
5400 REM - FIT X,D DATA TO LEAST SQUARES POLYNOMIALS AND PRINT RESULTS
5410 M1=2
5420 N4=0
5430 GOSUB 10000
5440 IF N4=1 THEN 5710
5450 PRINT
5460 PRINT
5470 PRINT USING 9430,M1,P$(M1)
5480 PRINT USING 9220
5490 FOR J=0 TO M1
5500 PRINT USING 9230,J,A(J+1,1)
5510 NEXT J
5520 PRINT USING 9240,E
5530 PRINT
5540 PRINT USING 9440
5550 PRINT USING 9450
5560 PRINT
5570 FOR J=1 TO P1
5580 SO=A(1,1)
5590 FOR K=1 TO M1
5600 SO=SO+A(K+1,1)*(R(J)^K)
5610 NEXT K
5620 PRINT USING 9460,F(J),R(J),U(J),SO,U(J)-SO
5630 NEXT J
5640 PRINT
5650 PRINT
5660 PRINT "FIT TO NEXT HIGHER ORDER POLYNOMIAL? (YES/NO)";
5670 INPUT X$
5680 IF X$="NO" THEN 5710
5690 M1=M1+1
5700 GOTO 5430
5710 PRINT
5720 PRINT "DESIRED ORDER OF FIT FOR USE IN EVALUATING RELATIVE "
5730 PRINT "PANEL DISPLACEMENT FOR POST IMPACT FRAMES ";
5740 INPUT M1
5750 PRINT
5760 PRINT
5770 GOSUB 10000
5780 REM - STORE COEFFICIENTS OF CURVE FIT FOR EACH SECTION LINE
5790 FOR I=0 TO M1
5800 O(I+1,I2)=A(I+1,1)
5810 NEXT I
5820 LIST USING 9300,I2,O(1,I2),O(2,I2),O(3,I2),O(4,I2),O(5,I2),E
5830 O(10,I2)=M1
5840 O(9,I2)=P1
```

```
5850 NEXT I2
5860 REM - COMPLETE PRINT OUT OF TITLE PAGE
5870 LIST USING 9750,CLK(H),DAT(W)
```

```
6000 REM - PRINTOUT FIRST PAGE OF DATA (FOR PRE-IMPACT FRAME)
6010 P7=2
6020 LIST USING 9610,S$,P7,NO+1
6030 LIST USING 9470
6040 LIST USING 9630
6050 LIST USING 9640
6060 LIST USING 9650
6070 LIST USING 9460
6080 FOR I2=1 TO N3
6090 LIST USING 9710,P$(I2+10)
6100 FOR I=1 TO O(9,I2)
6110 SO=D(1,I2)
6120 FOR J=1 TO O(10,I2)
6130 SO=SO+D(J+1,I2)*(W(I,I2)**J)
6140 NEXT J
6150 LIST USING 9690,H(I,I2),W(I,I2),E(I,I2),W(I,I2)-XO,E(I,I2)-SO
6160 NEXT I
6170 NEXT I2
6180 P7=P7+1
```

In the next segment of the program, fringe number-measured value pairs for all post event frames are processed. Page number, frame number, shot number, and the time after the event and other page heading information are printed first. Processed data for successive sections of each frame are then listed. As for the pre-event case, raw measured values are corrected for film magnification before they are listed. Only the corrected values are listed, however. In addition to fringe number and X and D values (in device coordinates) the listing includes X values referenced to the point of the event and displacement values referenced to the pre-event position of the target.

```
7000 REM - READ AND PRINT ALL FRAMES OF DATA AFTER PRE-IMPACT FRAMF
7010 FOR I1=1 TO NO-1
7020 READ N2
7030 PRINT N2;
7040 LIST USING 9610,S$,P7,NO+1
7050 FO=(N2/(F5+F6*N2+F7*N2^2))*1000
7060 LIST USING 9620,N2,FO
7070 LIST USING 9630
7080 LIST USING 9640
```

```
7090 LIST USING 9650
7100 LIST USING 9660
7110 FOR I2=1 TO N3
7120 READ P1
7130 IF P1=0 THEN 7330
7140 LIST USING 9710,P$(I2+10)
7150 FOR I=1 TO P1
7160 READ Q(I),P(I)
7170 F(I)=Q(I)
7180 P(I)=(M3+M4*P(I)+M5*P(I)^2)*25.4
7190 J=F1-Q(I)+1
7200 FOR K=1 TO N9+1
7210 IF X(K,J)<P(I) THEN 7230
7220 NEXT K
7230 P0=(X(K-1,J)-P(I))/(X(K-1,J)-X(K,J))
7240 Q(I)=D(K-1,J)+P0*(D(K,J)-D(K-1,J))
7250 GOSUB 15000
7260 S0=O(1,I2)
7270 FOR L=1 TO O(10,I2)
7280 S0=S0+O(L+1,I2)*(P(I)**L)
7290 NEXT L
7300 LIST USING 9690,F(I),P(I),Q(I),P(I)-X0,Q(I)-S0
7310 NEXT I
7320 GOTO 7340
7330 LIST USING 9720,P$(I2+10)
7340 NEXT I2
7350 P7=P7+1
7360 REM - GO TO NEXT FRAME AND PAGE OF PRINTOUT
7370 NEXT I1
8000 PRINT "JOB COMPLETED --  GOING TO 'END' STATEMENT"
8010 GOTO 20000
```

Following is a listing of the various image statements used in conjunction with the various PRINT USING and LIST USING commands. Content of these statements can be changed to suit the need of the user. Image statements listed and used for the sample problem were used for an aircraft transparency deflection measurement application.

```
9000 REM - IMAGE STATEMENTS FOR TITLE PAGE PRINTOUT
9010 :1                         F16-A BIRDSTRIKE PROGRAM
9020 :-          SHOT NUMBER -- ######################################
9030 :0           DATE FIRED -- ###############################
9040 :-         TRANSPARENCY -- ################################################
9050 :0           PROJECTILE -- #########################################
9060 :                WEIGHT -- #.## LBS
9070 :              VELOCITY -- ### KNOTS
9080 :-          ## FRAMES OF FILM (AFTER IMPACT) EVALUATED FOR THIS SHOT
9090 :-FOLLOWING ARE THE COEFFICIENTS OF LEAST-SQUARES POLYNOMIALS
9100 : OF THE FORM:
9110 :              Y = A0 + A1*X + ... + AN*X**N,
```

```
9120 :                                            FIT TO THE EXPERIMENTAL
9130 : DATA. FILM MAGNIFICATION, IN REAL INCHES, IS GIVEN AS A FUNCTION
9140 : OF MEASURED INCHES AND FILM SPEED, IN PICTURES PER SECOND, IS
9150 : GIVEN AS A FUNCTION OF FRAME NUMBER.
9160 :OCOEFFICIENTS:         A0               A1               A2          STD ER OF EST
9170 :OFILM MAGNIF:     -#.#####!!!!  -#.#####!!!!  -#.#####!!!!    #.#####!!!!
9180 :OFILM SPEED:      -#.#####!!!!  -#.#####!!!!  -#.#####!!!!    #.#####!!!!
9190 :-FUS STA 140 LOCATED ###.## MM TO THE RIGHT OF CENTER OF MOIRE DEVICE
9200 :-FUS STA 140 LOCATED ###.## MM TO THE LEFT OF CENTER OF MOIRE DEVICE
9210 : INSUFFICIENT DATA FOR FIT TO A # ##-ORDER POLYNOMIAL
9220 : PANEL DATA (REFERENCED TO THE MOIRE DEVICE).
9230 :                        A(#) = -#.#####!!!!
9240 :    STD. ERROR OF ESTIMATE = -#.#####!!!!
9250 :0                             PROGRAM RUN AT ###### HRS ON ######.
9260 :0         ** RESULTS OF CURVE FITS TO PRE-IMPACT PANEL SECTIONS **
9270 :                           (REFERENCED TO THE MOIRE DEVICE)
9280 :OSEC           COEFFICIENTS OF LEAST-SQUARE POLYNOMIALS            STD ERROR
9290 : NO     A(0)         A(1)         A(2)         A(3)         A(4)       OF EST


9300 : #    #.###!!!!   #.###!!!!   -#.###!!!!   -#.###!!!!   -#.###!!!!   -#.##!!!!
9400 REM - IMAGE STATEMENTS FOR PRINTOUT OF PRE-IMPACT PANEL DATA
9410 : FRINGE     MEASURED X,MM        DISPLACEMENT,MM      NO TIMES IN
9420 : NUMBER       RAW      CORR         RAW      CORR       SUBR COR
9430 : COEFFICIENTS OF A # ##-ORDER POLYNOMIAL FIT TO THE PRE-IMPACT
9440 : FRINGE   MEASURED      ACTUAL       CALCULATED     DIFFERENCE
9450 : NUMBER      X,MM       DISPL,MM      DISPL,MM      ACT - CALC
9460 :    ##    -##.###!!!!  -##.####!!!!  -##.####!!!!   -##.####!!!!
9470 :OFRAME NUMBER -- PRE-IMPACT
9600 REM - IMAGE STATEMENTS FOR ROUTINE DATA PAGES
9610 :1SHOT NUMBER  - ##################################      PAGE ## OF ## PAGES
9620 :OFRAME NUMBER -- ## (##.#### MSEC AFTER IMPACT)
9630 :              X-COORDINATE,  DISPLACEMENT,   X-COORDINATE,    DISPLACEMENT,
9640 : FRINGE          IN MM,           IN MM,          IN MM,            IN MM,
9650 : NUMBER     W/R TO MOIRE     W/R TO MOIRE       W/R TO         W/R TO PRESHOT
9660 :                DEVICE           DEVICE        FUS STA 140        POSITION
9670 :-
9680 :
9690 :  -##        -###.###          -##.###          -###.###           -##.###
9700 :  -##     -###.##   -###.##     -###.##   -###.##         ##
9710 :0#################################################################
9720 :ODATA NOT AVAILABLE FOR #############################################
```

In the following subroutine, LSQ, pairs of data are fit to a polynomial using a least-squares curve fitting routine. The sets of X_i and Y_i data are used to form the following series of equations:

$$\Sigma Y_i = A_o n + A_1 \Sigma X_i + \ldots + A_m \Sigma X_i^m$$

$$\Sigma X_i Y_i = A_o \Sigma X_i + A_1 \Sigma X_i^2 + \ldots + A_m \Sigma X_i^{m+1}$$

$$\vdots$$

$$\Sigma X_i^m Y_i = A_o \Sigma X_i^m + A_1 \Sigma X_i^{m+1} + \ldots + A_m \Sigma X_i^{2m}$$

In these equations, n is the number of data pairs, m is the order of the desired fit, and A_0, A_1, A_2 ... are coefficients of various terms in the equations. Since these equations are of the general form,

$$y = A_0 + A_1 X + A_2 X^2 + \ldots$$

they may be solved simultaneously to yield the various coefficients. In subroutine LSQ, this is accomplished by forming the various summations, placing the appropriate values in arrays, and using matrix algebra to solve for the coefficients. The various ΣX_i^m terms are formed in statement 10140 and later stored in array Y; the various $\Sigma X_i^m Y_i$ terms are formed in statement 10180 and stored in array T. Solution of the coefficients is accomplished in statements 10350 and 10360. Upon completion of a determination of the standard error of estimate for the fit using the following relationship,

$$\text{Std Error of Estimate} = \frac{\Sigma Y^2 - \Sigma A_m X^m Y}{n}$$

control is returned to the main program.

```
10000 REM - LEAST SQUARES SUBROUTINE
10010 REM - UP TO 50 DATA POINTS MAY BE FIT TO A 9TH ORDER POLYNOMIAL
10020 M2=M1+1
10030 IF M2>P1 THEN 10430
10040 MAT A=ZER(M2,1)
10050 MAT T=ZER(M2,1)
10060 MAT V=ZER(M2,M2)
10070 MAT Y=ZER(M2,M2)
10080 FOR J=0 TO 2*M1
```

```
10090 G(J)=0
10100 NEXT J
10110 S=Y2=0
10120 FOR N=1 TO P1
10130 FOR K=1 TO 2*M1
10140 G(K)=G(K)+P(N)^K
10150 NEXT K
10160 FOR L=1 TO M2
10170 IF L=1 THEN 10200
10180 T(L,1)=T(L,1)+Q(N)*(P(N)^(L-1))
10190 GOTO 10210
10200 T(1,1)=T(1,1)+Q(N)
10210 NEXT L
10220 Y2=Y2+Q(N)^2
10230 G(0)=N
10240 NEXT N
10250 L=M1
10260 FOR I=1 TO M2
10270 L=L+1
10280 J=I-1
10290 FOR K=1 TO L
10300 M=K-1
10310 N=K-J
10320 Y(I,N)=G(M)
10330 NEXT K
10340 NEXT I
10350 MAT V=INV(Y)
10360 MAT A=V*T
10370 FOR I=1 TO M2
10380 S=S+(A(I,1)*T(I,1))
10390 NEXT I
10400 Z=ABS(Y2-S)
10410 E=SQR(Z/G(0))
10420 GOTO 10450
10430 PRINT USING 9210,M1,P$(M1)
10440 N4=1
10450 RETURN
```

Film magnification correction terms were determined using data taken from the pre-event frame. When the target is deflected, a change in the magnification of its image occurs. Since the dark band used to define a measurement point is formed on the surface of the target, evaluation of the film magnification polynomial using post event measurements may yield results which are somewhat in error. Displacement values obtained with use of these measured values will also be in error. The magnitude of the error increases as the post event measurement plane is displaced in either direction from its pre-event position.

The error just described is reduced to a specified minimum value in subroutine COR using an iterative correction procedure. A graphical illustration of one step of the correction procedure is presented in Figure 11. In this procedure, use is made of the fact that each measured value lies on a line which makes a unique angle to the initial position of the target (or the X-axis). With respect to the illustration in Figure 11, angle α should equal angle β for this condition to be fulfilled. Angle α (A5, statement 15020) is the true angle which the line of sight makes with the pre-event target surface. Angle β (A6,

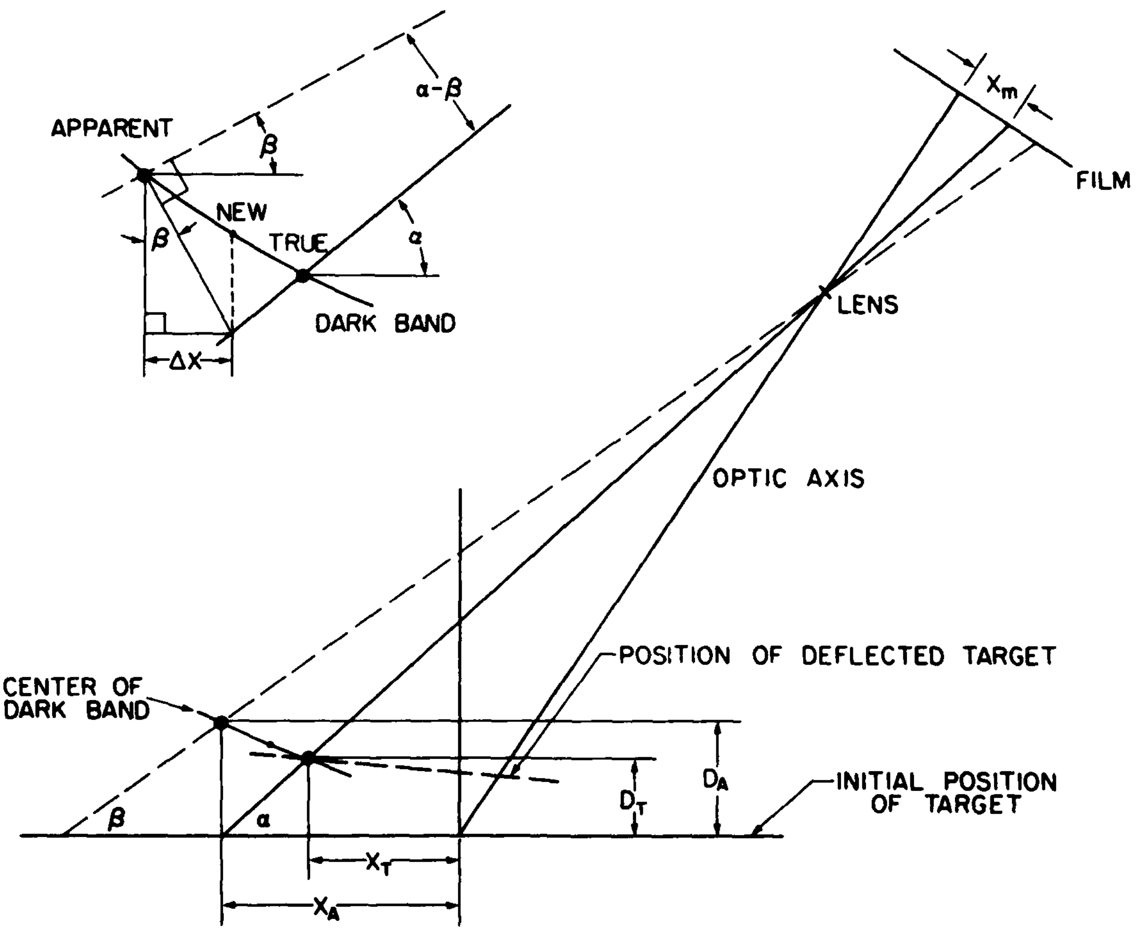

Figure 11. Illustration of Procedure Used to "Correct" Measured Values for Magnification Errors.

statement 15030) is the angle which an apparent line of sight makes with the pre-event target surface. These angles are determined in subroutine COR using device constants provided at the beginning of the program and the particular X_A and D_A values obtained from the initial interpolation of the tabulated X and D coordinates. The difference between these angles is compared with a specified minimum acceptable error (statement 15040). If the difference is less than the acceptable error, control is returned to the main program.

When a correction must be applied, the magnitude of the correction, ΔX (S2), is determined by making use of geometric relationships illustrated at the upper left of Figure 11 and expressed in statement 15050. The correction is applied to the old value of X_A *and the new* X_A *is used to determine a new value* of D_A by interpolation in the table of fringe coordinates. Note that use is made of the fact that the measured point must lie in the center of the dark band specified as the fringe number in the original data pair. The new values of X and D are used to compute a new angle β. The difference between α and the new β is compared with the minimum acceptable difference and, if necessary, the correction process is repeated. The examination and correction procedure is repeated until the difference between these angles is less than the minimum acceptable value.

```
15000 REM - SUBROUTINE FOR CORRECTION OF ERROR DUE TO MAGNIFCATION
15010 YO=0
15020 A5=ATN(R1/(R3-P(I)))
15030 A6=ATN((R1-Q(I))/(R3-P(I)))
15040 IF ABS(A5-A6)<5E-04 THEN 15140
15050 S2=(((R3-P(I))/COS(A6))*TAN(A5-A6))*SIN(A6)
15060 P(I)=P(I)+S2
15070 FOR K=1 TO N9+1
15080 IF X(K,J)<P(I) THEN 15100
15090 NEXT K
15100 PO=(X(K-1,J)-P(I))/(X(K-1,J)-X(K,J))
15110 Q(I)=D(K-1,J)+PO*(D(K,J)-D(K-1,J))
15120 YO=YO+1
15130 GOTO 15030
15140 RETURN

20000 END
```

SECTION V

TEST PROGRAM AND SAMPLE PRINTOUT

Except for order-of-fit data which are entered from the time-sharing terminal during a run, all data used during the execution of PANDIS are read from DATA statements. Statement numbers 1 through 999 are available for use as DATA statements Following is a listing of sample data which are read from these DATA statements. The data shown in these statements are used to produce the sample printout presented in this section.

An explanation of the data, by variable name, follows this listing.

```
 10 DATA 120.5,120.5,8,2.1954E-02,2.1954E-02
 20 DATA 1.0472,1.0472,6,5,.
 30 DATA ST,ND,RD,TH,TH,TH,TH,TH,TH
 31 DATA SECTION 1 INCH ABOVE IMPACT POINT
 32 DATA SECTION THROUGH IMPACT POINT
 33 DATA SECTION 1 INCH BELOW IMPACT POINT
 40 DATA TEST PROBLEM,OCTOBER 4 1980,CURVED LINES
 50 DATA IMAGINARY BALL,0,0,3
 60 DATA 8,2
 70 DATA 1.305,3.5,.83,2.5,.5,1.5,.16,.5,-.025,-.5
 80 DATA -.4,-1.5,-.625,-2.5,-.825,-3.5
 90 DATA 14,2,4.44
100 DATA 0,0,1,.86,2,1.72,3,2.58,4,3.44,5,4.3,6,5.17
110 DATA 7,6.03,8,6.9,9,7.77,10,8.64,11,9.5,12,10.37,13,11.24
130 DATA -.895
140 DATA 7
145 DATA -3,1.6,-2,1.185,-1,.715,0,.1,0,-.255,-1,-.66,-2,-.85
150 DATA 7
155 DATA -3,1.5,-2,1.085,-1,.615,0,0,0,-.355,-1,-.76,-2,-.95
160 DATA 7
165 DATA -3,1.4,-2,.985,-1,.515,0,-.1,0,-.455,-1,-.86,-2,-1.05
170 DATA 1
180 DATA 8
185 DATA -3,1.6,-2,1.29,-1,.92,0,.55,1,.01,1,-.25
190 DATA 0,-.65,-1,-.83
200 DATA 8
205 DATA -3,1.5,-2,1.19,-1,.82,0,.45,1,-.09,1,-.35
210 DATA 0,-.75,-1,-.93
220 DATA 8
225 DATA -3,1.4,-2,1.09,-1,.72,0,.35,1,-.19,1,-.45
230 DATA 0,-.85,-1,-1.03
240 DATA 2
250 DATA 0
260 DATA 9
265 DATA -3,1.59,-2,1.29,-1,.98,0,.68,1,.37,2,-.02
270 DATA 2,-.57,1,-.79,0,-.93
280 DATA 9
285 DATA -3,1.49,-2,1.19,-1,.88,0,.58,1,.27,2,-.12
290 DATA 2,-.67,1,-.89,0,-1.03
```

Statement Number	Variable Name/Description
10	R1, R2, N9, R8, R9
20	A1, A2, F1, F2, N3
	Statements 10 and 20 contain the six moiré device parameters and other values used to establish limits for subsequent computations and procedures. Note that N3 has a value of 3, indicating that profiles are to be obtained along three sections of each frame.
30	P$(1) to P$(9)
32	P$(11)
34	P$(12)
36	P$(13)
	Statements 32 through 36 are descriptions of the section lines which were used for each frame.
40	S$, D$, P$(0)
50	P$(10), Y8, Y9, N0
	Statements 40 and 50 contain descriptions of test target conditions and a specification of the number of frames which will be analyzed for the particular test.
60	P1, M1
	The number of points and the order of fit desired for the film magnification correction polynomial.
70	P(1), Q(1), P(2), R(2),...
80	P(6), Q(6), P(7), Q(7),...
	Data for film magnification determination
90	P1, M1, U(0)
	The number of points, the order of fit, and the distance to the first frame of the event. These values are used with the film speed data to determine the coefficients of a polynomial which describes the framing rate of the camera.
100	R(1), U(1), R(2), U(2),...
110	R(8), U(8), R(9), U(9),...
	Data for film speed determinations

Statement Number	Variable Name/Description
130	X0 Distance from origin of moiré device coordinate system to point of interest on target
140	P1 Number of data pairs for first section in pre-event frame
145	U(1), R(1), U(2), R(2),... Fringe number, measured value pairs for first section in pre-event frame
150,160	P1 Number of data pairs for remaining sections in pre-event frames
155,165	U(1), R(1), U(2), R(2),... Fringe number, measured value pairs for section in pre-event frame
170,250	N2 Frame numbers
180,200,220 250,260,280	P1 Number of data pairs for each section in the various post event frames. Note that a value of zero was entered in statement 250 indicating data were not available for this section.
All other statement numbers	Q(1), P(1), Q(2), P(2),... Data pairs for sections of all post event frames.

The next three pages are printout that was received at the the terminal during the run using the sample data. Only results of the analysis of certain pre-event data are printed at the terminal. These data are printed to permit the user to select best fit data for use during analysis of subsequent post event frames. In each of the pages the user was asked for a response after results of the first curve fit were printed. As shown, the response--YES--resulted in another printout and question. The negative response resulted in a request for specification of the order of fit to be used with the data that were presented at the beginning of the printout. A similar sequence was followed for the additional sections of the pre-event frame. At the end of the third page, the number of frames which had been processed and a notification that the job had been completed are printed to signify that work on the run has been terminated.

SAMPLE TERMINAL PRINTOUT - First Section

```
*RUN
> USED AS ARRAY & SCALAR NAME:E,H,M,N,W

SECTION 1-INCH ABOVE IMPACT POINT
```

FRINGE NUMBER	MEASURED X,MM RAW	MEASURED X,MM CORR	DISPLACEMENT,MM RAW	DISPLACEMENT,MM CORR	NO TIMES IN SUBR COR
-3	101.88	100.86	-24.02	-25.41	1
-2	82.30	79.88	-14.58	-17.05	2
-1	53.76	50.98	-8.80	-9.65	2
0	6.21	6.84	1.14	1.26	2
0	-26.51	-23.47	4.88	4.32	3
-1	-68.54	-68.37	0.35	0.26	1
-2	-89.99	-93.41	-6.72	-3.23	1

```
COEFFICIENTS OF A 2 ND-ORDER POLYNOMIAL FIT TO THE PRE-IMPACT
PANEL DATA (REFERENCED TO THE MOIRE DEVICE).
                          A(0) =  1.65370E+00
                          A(1) = -1.03775E-01
                          A(2) = -1.67575E-03
   STD. ERROR OF ESTIMATE =  8.38858E-01
```

FRINGE NUMBER	MEASURED X,MM	ACTUAL DISPL,MM	CALCULATED DISPL,MM	DIFFERENCE ACT - CALC
-3	10.086E+01	-25.4073E+00	-25.8591E+00	45.1782E-02
-2	79.880E+00	-17.0539E+00	-17.3286E+00	27.4673E-02
-1	50.983E+00	-96.4530E-01	-79.9291E-01	-16.5238E-01
0	68.370E-01	12.5744E-01	86.5855E-02	39.1583E-02
0	-23.472E+00	43.1690E-01	31.6630E-01	11.5061E-01
-1	-68.372E+00	25.5676E-02	91.5397E-02	-65.9720E-02
-2	-93.414E+00	-32.3170E-01	-32.7503E-01	43.3264E-03

```
FIT TO NEXT HIGHER ORDER POLYNOMIAL? (YES/NO)?YES


COEFFICIENTS OF A 3 RD-ORDER POLYNOMIAL FIT TO THE PRE-IMPACT
PANEL DATA (REFERENCED TO THE MOIRE DEVICE).
                          A(0) =  1.73528E+00
                          A(1) = -1.22948E-01
                          A(2) = -1.70283E-03
                          A(3) =  2.58886E-06
   STD. ERROR OF ESTIMATE =  7.07723E-01
```

FRINGE NUMBER	MEASURED X,MM	ACTUAL DISPL,MM	CALCULATED DISPL,MM	DIFFERENCE ACT - CALC
-3	10.086E+01	-25.4073E+00	-25.3306E+00	-76.7212E-03
-2	79.880E+00	-17.0539E+00	-17.6317E+00	57.7805E-02
-1	50.983E+00	-96.4530E-01	-86.1611E-01	-10.2919E-01
0	68.370E-01	12.5744E-01	81.5915E-02	44.1524E-02
0	-23.472E+00	43.1690E-01	36.4950E-01	66.7404E-02
-1	-68.372E+00	25.5676E-02	13.5380E-01	-10.9813E-01
-2	-93.414E+00	-32.3170E-01	-37.4904E-01	51.7338E-02

```
FIT TO NEXT HIGHER ORDER POLYNOMIAL? (YES/NO)?NO

DESIRED ORDER OF FIT FOR USE IN EVALUATING RELATIVE
PANEL DISPLACEMENT FOR POST IMPACT FRAMES ?3
```

SAMPLE TERMINAL PRINTOUT - Second Section

SECTION THROUGH IMPACT POINT

FRINGE NUMBER	MEASURED X,MM RAW	MEASURED X,MM CORR	DISPLACEMENT,MM RAW	DISPLACEMENT,MM CORR	NO TIMES IN SUBR COR
-3	97.64	95.55	-29.77	-32.61	2
-2	76.79	72.57	-20.20	-24.35	3
-1	46.82	42.82	-10.91	-12.12	3
0	-2.62	-2.40	0.48	0.44	1
0	-36.42	-32.02	6.70	5.89	3
-1	-79.70	-75.68	7.16	4.08	3
-2	-101.73	-99.00	5.26	2.47	2

COEFFICIENTS OF A 2 ND-ORDER POLYNOMIAL FIT TO THE PRE-IMPACT PANEL DATA (REFERENCED TO THE MOIRE DEVICE).

A(0) = -8.45184E-02
A(1) = -1.92726E-01
A(2) = -1.68482E-03
STD. ERROR OF ESTIMATE = 9.99634E-01

FRINGE NUMBER	MEASURED X,MM	ACTUAL DISPL,MM	CALCULATED DISPL,MM	DIFFERENCE ACT - CALC
-3	95.546E+00	-32.6095E+00	-33.8796E+00	12.7014E-01
-2	72.566E+00	-24.3455E+00	-22.9420E+00	-14.0352E-01
-1	42.825E+00	-12.1184E+00	-11.4279E+00	-69.0491E-02
0	-24.050E-01	44.2338E-02	36.9241E-02	73.0975E-03
0	-32.016E+00	58.8826E-01	43.5886E-01	15.2940E-01
-1	-75.676E+00	40.8426E-01	48.5154E-01	-76.7280E-02
-2	-98.998E+00	24.7134E-01	24.8279E-01	-11.4441E-03

FIT TO NEXT HIGHER ORDER POLYNOMIAL? (YES/NO)?YES

COEFFICIENTS OF A 3 RD-ORDER POLYNOMIAL FIT TO THE PRE-IMPACT PANEL DATA (REFERENCED TO THE MOIRE DEVICE).

A(0) = -1.35181E-01
A(1) = -2.20498E-01
A(2) = -1.66065E-03
A(3) = 3.73797E-06
STD. ERROR OF ESTIMATE = 7.54936E-01

FRINGE NUMBER	MEASURED X,MM	ACTUAL DISPL,MM	CALCULATED DISPL,MM	DIFFERENCE ACT - CALC
-3	95.546E+00	-32.6095E+00	-33.1026E+00	49.3179E-02
-2	72.566E+00	-24.3455E+00	-23.4523E+00	-89.3219E-02
-1	42.825E+00	-12.1184E+00	-12.3299E+00	21.1589E-02
0	-24.050E-01	44.2338E-02	38.5457E-02	56.8817E-03
0	-32.016E+00	58.8826E-01	50.9945E-01	78.8801E-02
-1	-75.676E+00	40.8426E-01	54.2099E-01	-13.3673E-01
-2	-98.998E+00	24.7134E-01	17.9169E-01	67.9655E-02

FIT TO NEXT HIGHER ORDER POLYNOMIAL? (YES/NO)?NO

DESIRED ORDER OF FIT FOR USE IN EVALUATING RELATIVE PANEL DISPLACEMENT FOR POST IMPACT FRAMES ?3

SAMPLE TERMINAL PRINTOUT - Third Section

SECTION 1-INCH BELOW IMPACT POINT

FRINGE NUMBER	MEASURED X,MM RAW	MEASURED X,MM CORR	DISPLACEMENT,MM RAW	DISPLACEMENT,MM CORR	NO TIMES IN SUBR COR
-3	93.10	89.54	-35.92	-40.75	2
-2	70.98	65.42	-25.06	-27.56	2
-1	39.57	34.17	-13.11	-14.74	3
0	-11.75	-10.57	2.16	1.94	2
0	-46.64	-40.57	9.17	7.46	4
-1	-91.15	-81.51	19.61	9.13	2
-2	-113.77	-104.38	24.48	7.97	3

COEFFICIENTS OF A 2 ND-ORDER POLYNOMIAL FIT TO THE PRE-IMPACT PANEL DATA (REFERENCED TO THE MOIRE DEVICE).

A(0) = -1.56133E+00
A(1) = -2.81086E-01
A(2) = -1.80357E-03
STD. ERROR OF ESTIMATE = 6.90966E-01

FRINGE NUMBER	MEASURED X,MM	ACTUAL DISPL,MM	CALCULATED DISPL,MM	DIFFERENCE ACT - CALC
-3	89.540E+00	-40.7533E+00	-41.1898E+00	43.6462E-02
-2	65.422E+00	-27.5633E+00	-27.6699E+00	10.6613E-02
-1	34.169E+00	14.7423E+00	-13.2713E+00	-14.7100E-01
0	-10.566E+00	19.4321E 01	12.0721E-01	73.5997E-02
0	-40.567E+00	74.6073E-01	68.7330E-01	58.7427E-02
-1	-81.507E+00	91.2654E-01	93.6728E-01	-24.0739E-02
-2	-10.438E+01	79.7279E-01	81.2773E-01	-15.4938E-02

FIT TO NEXT HIGHER ORDER POLYNOMIAL? (YES/NO)?YES

COEFFICIENTS OF A 3 RD-ORDER POLYNOMIAL FIT TO THE PRE-IMPACT PANEL DATA (REFERENCED TO THE MOIRE DEVICE).

A(0) = -1.71183E+00
A(1) = -2.99229E-01
A(2) = -1.74331E-03
A(3) = 2.52445E-06
STD. ERROR OF ESTIMATE = 5.28980E-01

FRINGE NUMBER	MEASURED X,MM	ACTUAL DISPL,MM	CALCULATED DISPL,MM	DIFFERENCE ACT - CALC
-3	89.540E+00	-40.7533E+00	-40.6694E+00	-83.8928E-03
-2	65.422E+00	-27.5633E+00	-28.0425E+00	47.9263E-02
-1	34.169E+00	-14.7423E+00	-13.8706E+00	-87.1632E-02
0	-10.566E+00	19.4321E-01	12.5216E-01	69.1051E-02
0	-40.567E+00	74.6073E-01	73.8944E-01	71.2891E-03
-1	-81.507E+00	91.2654E-01	97.2894E-01	-60.2397E-02
-2	-10.438E+01	79.7279E-01	76.5639E-01	31.6407E-02

FIT TO NEXT HIGHER ORDER POLYNOMIAL? (YES/NO)?NO

DESIRED ORDER OF FIT FOR USE IN EVALUATING RELATIVE
PANEL DISPLACEMENT FOR POST IMPACT FRAMES ?3

1 2 JOB COMPLETED--- GOING TO 'END' STATEMENT
*

The next four pages present the sample printout produced at the high-speed printer. Presentation of these pages completes instructions for the use of the moiré device and program PANDIS.

```
                         F16-A BIRDSTRIKE PROGRAM



          SHOT NUMBER -- TEST PROBLEM

           DATE FIRED -- OCTOBER 4 1980


         TRANSPARENCY -- CURVED LINES

           PROJECTILE -- IMAGINARY BALL
               WEIGHT -- 0.00 LBS
             VELOCITY --    0 KNOTS

           0 FRAMES OF FILM (AFTER IMPACT) EVALUATED FOR THIS SHOT


  FOLLOWING ARE THE COEFFICIENTS OF LEAST-SQUARES POLYNOMIALS
  OF THE FORM:
            Y = A0 + A1*X + ... + AN*X**N,
                                        FIT TO THE EXPERIMENTAL
  DATA. FILM MAGNIFICATION, IN REAL INCHES, IS GIVEN AS A FUNCTION
  OF MEASURED INCHES AND FILM SPEED, IN PICTURES PER SECOND, IS
  GIVEN AS A FUNCTION OF FRAME NUMBER.

  COEFFICIENTS:          A0            A1            A2          STD ER OF EST

  FILM MAGNIF:     -1.02975E-01   3.535125E+00  -6.02448E-01    7.09260E-02

  FILM SPEED:       2.58027E+03   1.248854E+00  -2.78473E-02    6.92870E+00



  FUS STA 140 LOCATED  95.24 MM TO THE RIGHT OF CENTER OF MOIRE DEVICE

          ** RESULTS OF CURVE FITS TO PRE-IMPACT PANEL SECTIONS **
                      (REFERENCED TO THE MOIRE DEVICE)

  SEC             COEFFICIENTS OF LEAST-SQUARE POLYNOMIALS                STD ERROR
  NO      A(0)          A(1)          A(2)          A(3)         A(4)         OF EST

  1    1.735E+00   -1.229E-01   -1.703E-03    2.589E-06    0.000E+00     7.08E-01
  2   -1.352E-01   -2.205E-01   -1.661E-03    3.738E-06    0.000E+00     7.55E-01
  3   -1.712E+00   -2.992E-01   -1.743E-03    2.524E-06    0.000E+00     5.29E-01

                          PROGRAM RUN AT 161105 HRS ON 110580.
```

SAMPLE PRINTOUT - Title Page

SHOT NUMBER -- TEST PROBLEM PAGE 2 OF 4 PAGES

FRAME NUMBER -- PRE-IMPACT

FRINGE NUMBER	X-COORDINATE, IN MM, W/R TO MOIRE DEVICE	DISPLACEMENT, IN MM, W/R TO MOIRE DEVICE	X-COORDINATE, IN MM, W/R TO FUS STA 140	DISPLACEMENT, IN MM, W/R TO PRESHOT POSITION
SECTION 1-INCH ABOVE IMPACT POINT				
-3	100.853	-25.407	196.095	-0.077
-2	79.880	-17.054	175.117	0.576
-1	50.983	-9.645	146.220	-1.029
0	6.837	1.257	102.074	0.442
0	-23.472	4.317	71.765	0.667
-1	-66.372	0.256	26.865	-1.096
-2	-93.414	-3.232	1.823	0.517
SECTION THROUGH IMPACT POINT				
-3	95.546	-32.610	190.763	0.493
-2	72.566	-24.746	167.803	-0.893
-1	42.825	-12.118	138.062	0.212
0	-2.405	0.442	92.832	0.057
0	-32.016	5.688	63.221	0.789
-1	-75.676	4.064	19.561	-1.337
-2	-98.998	2.471	-3.761	0.680
SECTION 1-INCH BELOW IMPACT POINT				
-3	89.540	-40.753	184.777	-0.084
-2	65.422	-27.563	160.659	0.479
-1	34.169	-14.742	129.405	-0.872
0	-10.566	1.943	84.671	0.691
0	-40.567	7.461	54.670	0.071
-1	-81.507	9.127	13.730	-0.602
-2	-104.384	7.973	-9.147	0.316

SAMPLE PRINTOUT Cont'd - Pre-event Frame

SHOT NUMBER -- TEST PROBLEM PAGE 3 OF 4 PAGES

FRAME NUMBER -- 1 (0.3470 MSEC AFTER IMPACT)

FRINGE NUMBER	X-COORDINATE, IN MM, W/R TO MOIRE DEVICE	DISPLACEMENT, IN MM, W/R TO MOIRE DEVICE	X-COORDINATE, IN MM, W/R TO FUS STA 140	DISPLACEMENT, IN MM, W/R TO PRESHOT POSITION
SECTION 1-INCH ABOVE IMPACT POINT				
-3	100.658	-25.407	196.095	-0.077
-2	86.576	-10.214	151.815	9.779
-1	66.683	-0.861	162.120	12.469
0	45.006	8.277	140.243	15.289
1	10.521	21.037	105.758	20.781
1	-12.154	19.462	63.083	16.509
0	-54.631	13.900	40.606	10.953
-1	-79.955	7.441	15.282	8.085
SECTION THROUGH IMPACT POINT				
-3	95.546	-32.610	190.783	0.493
-2	80.218	-16.709	175.455	5.871
-1	59.011	-6.963	154.247	11.176
0	37.303	6.860	132.540	17.338
1	2.015	20.317	97.251	20.903
1	-19.610	21.407	75.627	17.885
0	-61.090	17.722	34.147	11.437
-1	-85.091	13.020	10.146	6.720
SECTION 1-INCH BELOW IMPACT POINT				
-3	89.540	-40.753	184.777	-0.094
-2	72.933	-24.148	168.170	7.681
-1	51.372	-9.527	146.609	11.615
0	29.257	5.361	124.494	17.276
1	-6.917	10.561	88.720	19.287
1	-27.051	23.728	68.186	16.271
[illegible]	-67.515	21.524	27.722	11.757
-1	-90.010	18.364	5.727	9.107

SAMPLE PRINTOUT Cont'd - Frame #1

SHOT NUMBER -- TEST PROBLEM　　　　　　　　　　　　PAGE 4 OF 4 PAGES

FRAME NUMBER -- 2 (0.6938 MSEC AFTER IMPACT)

FRINGE NUMBER	X-COORDINATE, IN MM, W/P TO MOIRE DEVICE	DISPLACEMENT, IN MM, W/R TO MOIRE DEVICE	X-COORDINATE, IN MM, W/P TO FUS STA 140	DISPLACEMENT, IN MM, W/P TO PRESHOT POSITION
DATA NOT AVAILABLE FOR SECTION 1-INCH ABOVE IMPACT POINT				
SECTION THROUGH IMPACT POINT				
-3	100.372	-26.066	195.609	9.151
-2	86.578	-10.214	181.815	19.033
-1	71.099	2.417	166.336	25.281
0	55.796	14.589	151.033	31.546
1	39.523	25.937	134.760	37.147
2	17.509	36.571	112.746	41.056
2	-25.286	37.927	69.949	33.609
1	-52.044	29.985	42.393	23.657
0	-72.587	24.525	27.650	16.835
SECTION 1-INCH BELOW IMPACT POINT				
-3	94.981	-33.375	190.218	10.322
-2	80.218	-16.709	175.455	18.922
-1	63.810	-3.251	159.047	23.997
0	47.619	9.751	142.856	29.392
1	31.192	22.787	126.428	35.452
2	10.049	36.571	105.286	41.463
2	-31.916	40.069	63.321	34.099
1	-56.518	33.683	36.719	24.360
0	-75.771	29.165	15.466	18.377

SAMPLE PRINTOUT Concluded - Frame #2

REFERENCE

Piekutowski, A. J., A Device to Determine the Out-of-Plane Displacement of a Surface Using a Moiré Fringe Technique, AFWAL-TR-81-3005, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, OH, May 1981.

DATE
FILMED
-8